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THE ELEVATOR ILLUSION: APPARENT MOTION OF A VISUAL TARGET DURING VERTICAL ACCELERATION

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Research Report

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MOTION OF A VISUAL TARGET DURING VERTICAL ACCELERATION*

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SUMMARY PAGE

THE PROBLEM

Two normal and two labyrinthine defective subjects were exposed to vertical accelerations of either less than 1 G or more than 1 G on descent or ascent, respectively, in an elevator. Three targets were utilized: a real target alone, a visual afterimage alone, and a combination of both.

FINDINGS

In general, it was found that normal subjects tend to perceive illusory movement of real targets and visual afterimages during vertical acceleration greater and less than 1 G. Real target apparent movement is downward when $G < 1$ and upward when $G > 1$; for a visual afterimage the directional relationships are reversed. There is no well-defined displacement of a real target whereas marked displacement occurs with a visual afterimage. When viewed in combination, the same relationships are maintained.

For subjects lacking vestibular function, there is no apparent movement of real targets at any time. Both movement and displacement may be perceived when visual afterimages are viewed singly or together, but the reports tend to be uncertain and conflicting even for the same observer on successive trials.

Further experiments carried out on three normal subjects and one bilateral labyrinthine defective who had lost vestibular function in adult life revealed that, in the change from 1 G to zero G, there is an involuntary upward eye movement in normals which lasts at least 150 milliseconds. The failure to demonstrate this in the labyrinthine defective subject suggests therefore that the change is reflexive and probably otolithic in origin.

A comparison suggests that the elevator illusion is a special condition of the oculogravic illusion in which the resultant vector changes only in magnitude and not in direction.

INTRODUCTION

The apparent movements and displacements of a target which are seen when one is subjected to accelerations which change in magnitude or direction have been described in numerous investigations. Less well established is the apparent behavior of the target when only magnitude of acceleration is altered. In response to this stimulus, an "elevator illusion" has been described, in which there is apparent displacement of the walls of an elevator relative to the observer, the illusion being that of a relative downward movement with diminishing acceleration, or an upward illusory movement in response to increasing acceleration (3).

While these effects of changed magnitude of acceleration can be studied using a human centrifuge with the cab free to align itself with the changing direction of resultant force, or using an aircraft performing a parabolic flight maneuver, it is difficult to avoid the complications of additional angular or linear accelerations. It is therefore best to use devices such as elevators which are capable of imparting a linear acceleration acting in the same axis as the acceleration due to gravity, although not necessarily of the same sign. In the first part of the present study on the occurrence of the illusion in both normal and labyrinthine defective subjects, the stimulus was therefore produced by high speed elevators, while in the second part a zero G tower was used to determine the role of eye movement in the production of the illusion.

Four trained subjects participated in the experiment on the high speed elevator. Two, a woman aged 42 and a man aged 47, were deaf and without labyrinthine response to stimulation by angular acceleration or irrigation of the external auditory meatus by ice water. The remaining two subjects, men aged 44 and 58, had no detectible defects of the inner ear and acted as experimenters as well as subjects. In the experiments on eye movement in the zero G tower, four male subjects took part. Three of these, aged 31, 37, and 40 years, had no demonstrable vestibular defect, while the fourth subject, aged 25 years, was without detectible labyrinthine function as a result of treatment to relieve an acute infective condition some five years previously.

THE VISUAL ILLUSION

APPARATUS

The experiments were carried out in a 1200 fpm elevator of the Empire State Building in New York and a 750 fpm elevator of the Waterman Building in Mobile, Alabama, in the summer and fall of 1960. In both vehicles, accelerations downward resulted in approximately an 0.2G decrease. Accelerations upward could not be measured with the available instrument, a Bourns potentiometer type linear accelerometer with a range of ± 1.0G. A Heiland four-channel airborne oscillograph was used. One channel was used for the acceleration, one for a timing marker, and the remaining two for event markers.

The target device consisted of a 2-inch metal cylinder in which was mounted a clear plastic diaphram recessed about 3/4 inch behind the face. On this diaphragm was mounted a target lamp. Attached to the face was a metal holder 2"x2" containing slots for reticles. On the back of the cylinder was mounted a hinged door supporting a miniature photographic flash unit. A number of target reticles were prepared from brass shim. This target device was supported at appropriate height on the wall of the elevator by means of 4 suction cups attached to a metal holding bracket. In addition, the bracket supported a biting board which fixed the position of the subject's head with his eyes about 20 inches from the reticle in the Empire State Building trials and 58 inches in the Waterman Building trials. This method of attachment was sufficiently rigid to prevent any obvious motion of the equipment during the experimental runs.

PROCEDURE

Experiments were carried out in darkness upon beginning ascent or descent using the following test situations:

1. Subject observing a real target (spot within an illuminated ring).
2. Subject observing a real target (spot) surrounded by a visual afterimage of the ring.
3. Subject observing the visual afterimage of the ring alone.

The experimental sequence was as follows:

1. Subject fixated target and signalled readiness for test to begin. When a visual afterimage was used, the subject himself triggered the flash when ready.

2. Prior to the start, the subject reported any target movement and/or displacement of an autokinetic nature, and when the visual afterimage was used, he reported whether it was concentric with the real target.

3. Within five seconds of these reports, the elevator was put into motion.

4. On first perceiving motion of elevator, the subject pressed a signal button in his left hand, and when the first vertical displacement of target was seen, he pressed a signal button in his right hand. When target reversed direction and/or ceased to move, he again signalled with the right-hand button.

5. Immediately after the experimental trial, the subject reported on his observation with the aid of a work sheet listing the task items and depicting the reference frame. The experimenter checked the work sheet and interrogated the subject regarding other observations of interest.

RESULTS

Real Target

The results obtained with a real target comprising a point of light centered within an illuminated ring are summarized in Table 1. The observations in both the Empire State and Waterman Building elevators were essentially the same for the labyrinthine-defective subjects, although in the former the target viewing distance was 20 inches and in the latter, 58 inches. Both subjects PH and RG denied consistent motions of the target, but each reported observing random short movements of varied direction, usually in the horizontal plane. They were aware, however, of elevator movement and correctly reported its direction on the majority of occasions, presumably through accessory cues and a general knowledge of the progress of the experiment.

Of the normal subjects, only AG was able to signal both start and stop of apparent movement, which was directed downward on starting to descend(<1 G) and upward (>1 G) on starting to ascend. Actual displacement was either not observed or very indefinite. The duration of apparent movement ranged from five to nine seconds. The second subject, JN, also perceived apparent movement but was not able to signal its termination because of uncertainty as to the end point. No displacement was observed, but the direction of movement was very definite and coincided with that reported by AG. Both subjects were clearly aware of the general movement of the elevator and never erred with respect to its direction.

Real Target and Visual Afterimage

The second series of experiments was carried out using both a real point target and an annular visual afterimage (see Table II). Again the labyrinthine-defective subjects did not report any consistent movement or displacement of the target although PH reported from time to time a small deviation upward on descent and downward on ascent. Not only were these deviations negligible in duration (less than a second) and magnitude, but occasional reversals occurred. RG consistently reported "point centered at all times," although at times it "vibrated."

Subject JN, one of the normal controls, reported consistent displacements of the point downward relative to the afterimage on beginning descent and upward on beginning ascent. The magnitude of the displacement averaged one half to three quarters of the ring radius, with durations of four and five seconds on ascent and descent, respectively. Similar results were reported by AG with respect to direction of displacement. Duration was, however, noticeably longer, and the magnitude was larger on descent and less on ascent.

Visual Afterimage (VAI)

In a third series of experiments, only a visual afterimage of a ring target was presented. The results in this experiment are the most difficult to interpret as may be seen

Table I

Behavior of Real Target (Point in Ring)
During Vertical Accelerations

			Movement of Target			
			Direction		Duration, in Seconds	
Subject	Elevator Travel from Rest	G	ES	W	ES	W
JN	Down	< 1	Down		?	
	Up	> 1	Up		?	
AG	Down	< 1	Down		5.7	
	Up	> 1	Up		7.2	
PH	Down	< 1	0	0 or Up	0	0
	Up	> 1	0	0	0	0
RG	Down	< 1	0	0 or Up	0	0
	Up	> 1	0	0 or Down	0	0

ES indicates Empire State Building (New York) elevator experiments and W indicates Waterman Building (Mobile) elevator experiments done on PH and RG only

?=Termination of movement uncertain

Table II

Behavior of Real Target (Point) Relative to
Visual Afterimage (Ring) during Vertical Accelerations

			Movement of Real Target Relative to Visual Afterimage					
	Elevator Travel		Direction		Duration in Seconds		Displacement in Ring Diameters	
Subject	from Rest	G	ES	W	ES	W	ES	W
JN	Down	< 1	Down		5.0		0.7	
	Up	> 1	Up		4.1		0.5	
AG	Down	< 1	Down		9.0		1.2	
	Up	> 1	Up		7.0		Negligible	
PH	Down	< 1	0	0 or down	0	oo	0	0 to 6
	Up	> 1	0	0 or down	0	oo	0	0 to 0.5
RG	Down	< 1	0	Up to down	0	3 to oo	0	0 to 0.5
	Up	> 1	0	Up to down	0	3 to oo	0	0 to 0.5

ES indicates Empire State Building (New York) elevator experiments and W indicates Waterman Building (Mobile) elevator experiments done on PH and RG only

oo indicates movement without displacement throughout the run

Table III

Behavior of a Visual Afterimage (Ring) during Vertical Accelerations

Subject	Elevator Travel from Rest	G	Direction ES	Direction W	Duration, in Seconds ES	Duration, in Seconds W	Displacement, in Ring Diameters ES	Displacement, in Ring Diameters W
JN	Down	< 1	Up		9.1		+	
	Up	> 1	Down		14.0		+	
AG	Down	< 1	Up		11.7		1/2 to +	
	Up	> 1	Up		? to oo		0	
PH	Down	< 1	Up	Up	13.8 to oo	oo	0	4-8
	Up	> 1	Up	Up	oo	0	0	1.5-10
RG	Down	< 1	Up	Up	11.8	3.9	?	4-10
	Up	> 1	Up	Up	9.2	7.0	?	3-10

ES indicates Empire State Building (New York) elevator experiments and W indicates Waterman Building (Mobile) elevator experiments done on PH and RG only

+ indicates displacement to periphery of field

oo indicates movement without displacement throughout the run from Table III. Subject JN reported consistently a VAI motion contrary to that of the elevator and of the real target observed alone. Subject AG was in agreement during the descents at less than 1 G but on two of three trials perceived the VAI movement upward on ascent. It may be noted, however, that he was also uncertain in his judgments with respect to duration and magnitude. The labyrinthine-defective subjects always reported VAI motion upward regardless of stimulus direction. PH, however, tended to observe movement continuously throughout the run, whereas the movement perceived by RG tended to be equal to or less than that for JN, although in the opposite sense during ascent. Both PH and RG either saw no displacement or were uncertain as to its magnitude on the Empire State tests, whereas the displacement was generally extreme on the Waterman runs. It is possible but not certain that this difference was related to the longer viewing distance for the latter.

EYE MOVEMENT

Although, with respect to the target, the head was well immobilized in the preceding experiments, there was still the possibility that involuntary eye movement of a compensatory nature might play a part in its production. Accordingly, observations were made but using a zero G tower at Farnborough since it could in theory provide a step acceleration from one to zero G as the cage was released.

It seemed probable that any eye movement occurring as a result of the change in acceleration acting in the vertical sense would also be in the vertical direction; so, in view of the difficulties inherent in recording especially small ocular movements in this plane, it was decided to employ a technique described by Barlow (1).

APPARATUS

This consists of presenting to right and left of a fixation point, lines of light produced by the discharge of flash tubes. If the lines to left and right of the fixation point do not flash simultaneously, and if an eye movement at right angles to the line has taken place between the two flashes, subsequent inspection of the afterimage will reveal that the two lines are no longer end to end but are displaced, one being above the other. The detection of this displacement amounts to a task involving vernier acuity, so it is relatively easy to detect even a small misalignment of the two afterimages. Such a technique thus gives a direct measurement of displacement of the image on the retina.

The apparatus to produce the two flashes is shown in Figure 1. The flash tubes are mounted in separate compartments behind the front panel and as close to the viewing slits as possible. These slits are separated by a 1/16" thick baffle which also prevents the light being transmitted by total internal reflection from one slit to the other through the plastic diffuser which covers these slits. In front of the center point is a thin glass sheet mounted at approximately 45° to the front panel and so arranged that the subject sees, by partial reflection off this plate, a fixation light also mounted on the front panel and so aligned that it appears to be between the two slits. The start of drop was signalled by a simple accelerometer consisting of a mass on the end of a flat spring. The break of an electrical circuit as the accelerometer mass moved up produced a step change of voltage which could be displayed on one beam of a cathode ray tube. This simple device thus signalled the step from 1 G to 0 G – a measurement which was uncomplicated by considerations of frequency response of the instrument.

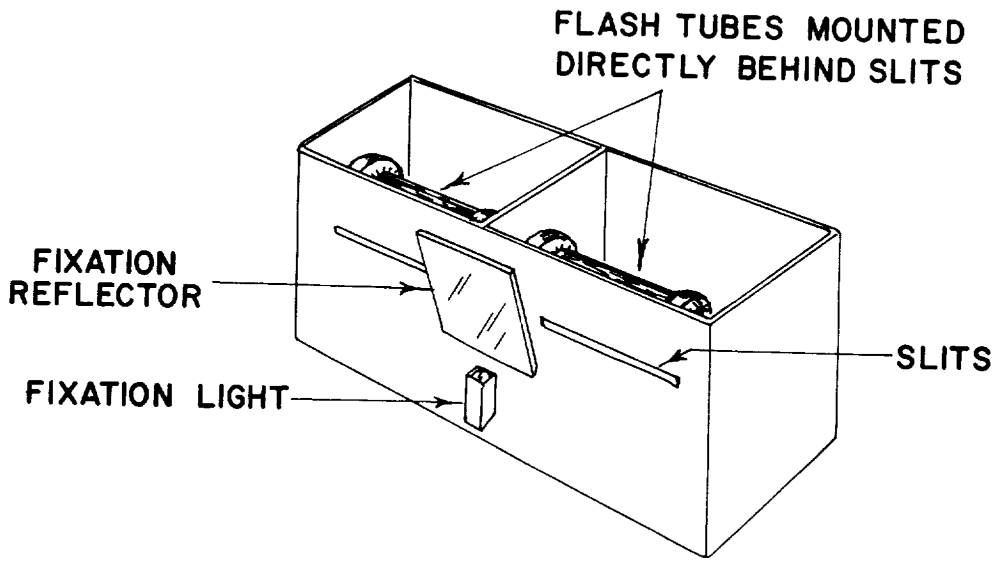


Figure 1

Diagrammatic Representation of Double Flash Unit

The timing of all events was effected by a simple electro-mechanical system whereby a heavy weight dropping between guide rails operated a number of electrical switches in the course of its fall. Since this weight was very heavy by comparison with the mechanical resistance caused by the switches, these did not measurably affect the velocity of its fall. However, as a check against the accuracy of timing, the start of drop as indicated by the accelerometer, the initiation of the first flash, then of the second flash were displayed on a cathode ray tube and photographed for a subsequent analysis.

The lift cabin descended between guide rails to ensure that it dropped without torsion. It was suspended from an electro-mechanical bomb release which, when energised, allowed the cabin to fall a maximum of 6 feet. Beyond this distance, deceleration was accomplished by means of elastic cords. In practice, for the present experiments, it was sufficient to drop the cabin 12 inches as this gave about 250 milliseconds of free fall.

PROCEDURE

The subject was seated in the cabin, and his head was immobilised as far as possible by an individually moulded plaster cap, the flat top of which butted on to a head restraining girder bolted horizontally across and forming part of the structure of the cabin. Instructions for immobilising were that the subject had to press the vertex of his head hard against the cross girder and also press the head back against the seat. The deceleration at the end of the drop (by which time all observations had been made) precluded the regular use of a dental bite.

The first flash was timed to take place within 5 milliseconds before the start of the drop, this being signalled on a cathode ray oscilloscope as are already described. The second flash was made to take place at varying times from 0 to 110 milliseconds after the start of the drop. The subject did not know what the timing sequence was, this being chosen randomly.

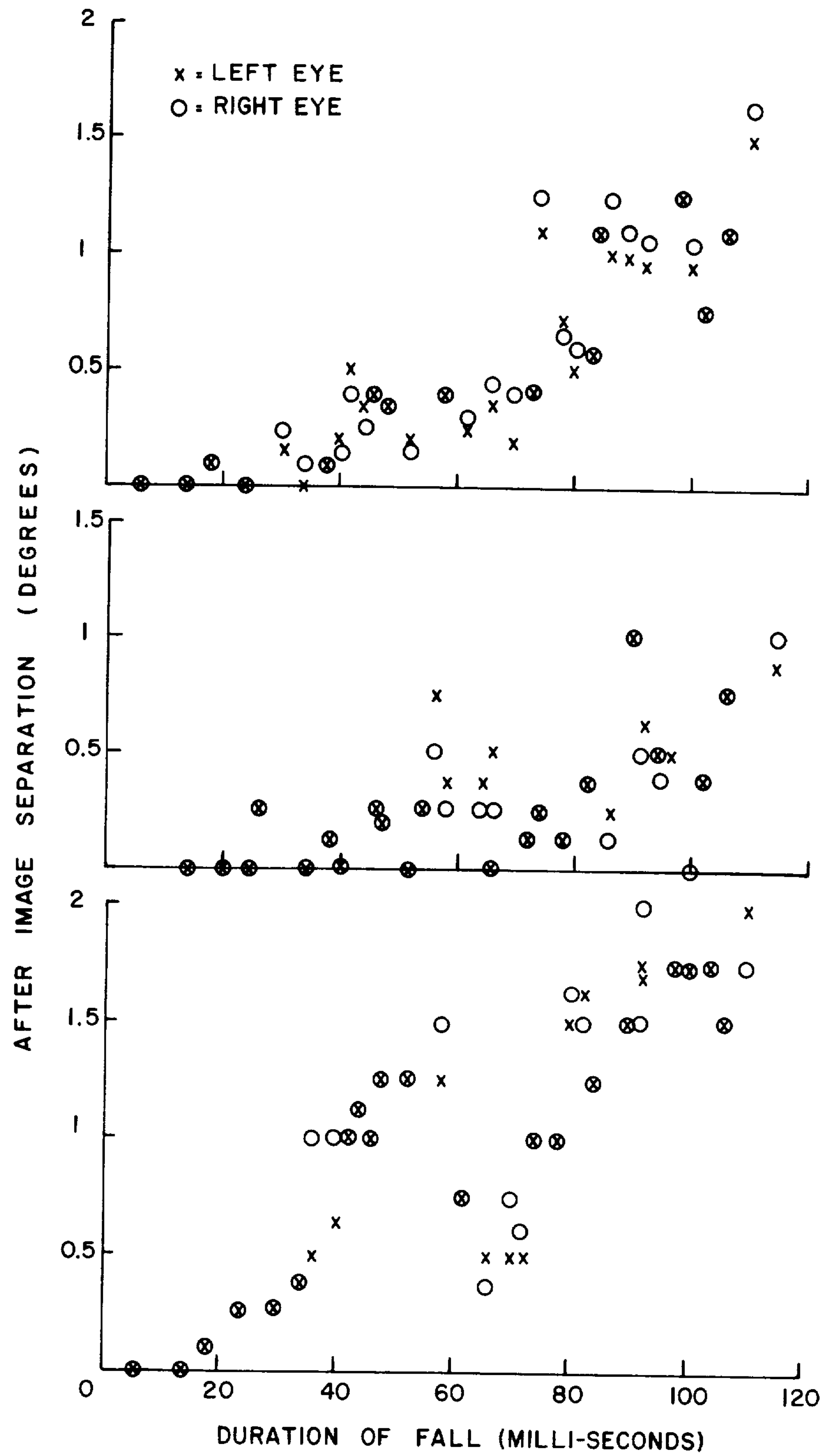
After each drop, the subject observed a lined card at a predetermined distance, and against this he measured the separation of the afterimage.

It required some practice to determine the separation of the afterimages, but the measurements could be made to within 10 minutes of arc and sometimes even to less than this (about 7 minutes of arc).

RESULTS

The results from the three normal subjects are shown in Figures 2, 3, and 4. They show that, up to about 30 milliseconds from the start of the drop, there was no consistent separation of the afterimages but that with increasing time from the start of the drop, the separation of the afterimages tended to increase, becoming greatest at about 80-100 milliseconds after the start of the drop. This separation of afterimages indicated a deviation of the eyes in the upward direction. No results were obtained after 120 milliseconds since it was felt that the two-flash technique would lose accuracy if the second flash came so long after the first that it could show an involuntary eye movement in response to the startle produced by the first flash. Since it was considered inadvisable to inflict on the labyrinthectomised subject, who had kindly consented to take part in the investigation, the tedium and extreme discomfort of the entire series of 30 drops, he was dropped only three times, the second flash appearing 50 milliseconds after the start of the drop. On the first and last drops, he saw no misalignment of the two afterimages, while in the second drop, he reported only a small deviation equivalent to 7 minutes of arc.

Figures 2, 3, and 4 also show, about 60-70 milliseconds after the start of the drop, a reduction in the separation of the afterimages. This surprising result suggested a possible uncontrolled physical artifact in the experimental technique. Accordingly, the characteristics of the free fall were examined employing an accelerometer which



Figures 2, 3, and 4

could give quantitatively the acceleration profile of the falling cabin. This accelerometer was placed on the head support girder.

As will be seen from Figure 5, the accelerometer revealed that, for about 20 milliseconds after the start of the drop, the head support girder accelerated downward from + 1G through 0G, to a peak of -1G. This was followed by a return to about +0.4G at 40 milliseconds after which in a series of small oscillations, it came to 0G at about 60-70 milliseconds. It is probable that this curious pattern of acceleration was due to the head support girder and the roof of the cage being suddenly released from strain as the bomb release detached itself from its attachment point in the roof of the cage. After springing downwards and imparting -1G to the head and head support, it terminated its movement by imparting a second thrust from +0.4G to 0G. The head would thus be thrust down on two successive occasions before reaching 0G.

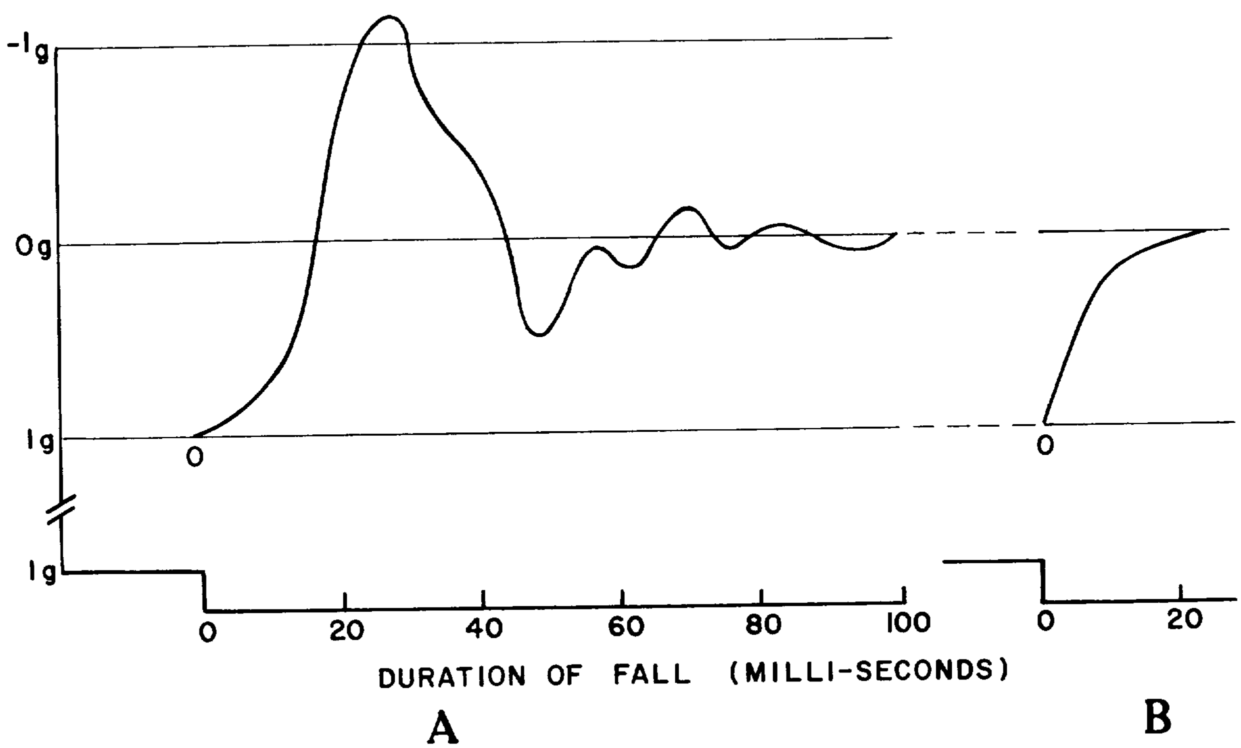


Figure 5

The limits imposed by the accelerometer's frequency response, however, prevent it from showing the rapidity of onset of these accelerations. In Figure 5 for comparison, there is seen the response to what should be a step from 1G to 0G as the accelerometer itself is dropped.

The results relating to eye movements may thus be regarded as exhibiting the response to two accelerations separated in time.

In order to determine whether any of the results on separation of afterimage were due to movement of the head rather than of the eyes, a further experiment was carried out with the flash unit 1/3 of the distance at which it had been employed previously. In this way the presence of any translational movement of the eye, of the head, or even the translational component of a rotation of the head about the atlanto-occipital joint, would cause the afterimage to be more displaced than when the flash unit was further from the eye. On the other hand, if separation of the afterimages was due solely to rotation of the eyes or to the unlikely event of rotation of the head precisely about the nodal point of the eyes, then there would be no difference in the angular separation of the afterimages.

The results of this experiment are seen in Figure 6. This shows that while the maximum separation of afterimages is somewhat greater than that seen in Figure 4 (the same subject), generally the separation does not differ greatly. If the results had been due solely to head movement, they would of course have been trebled as the distance from flash unit to the eyes was reduced by one-third.

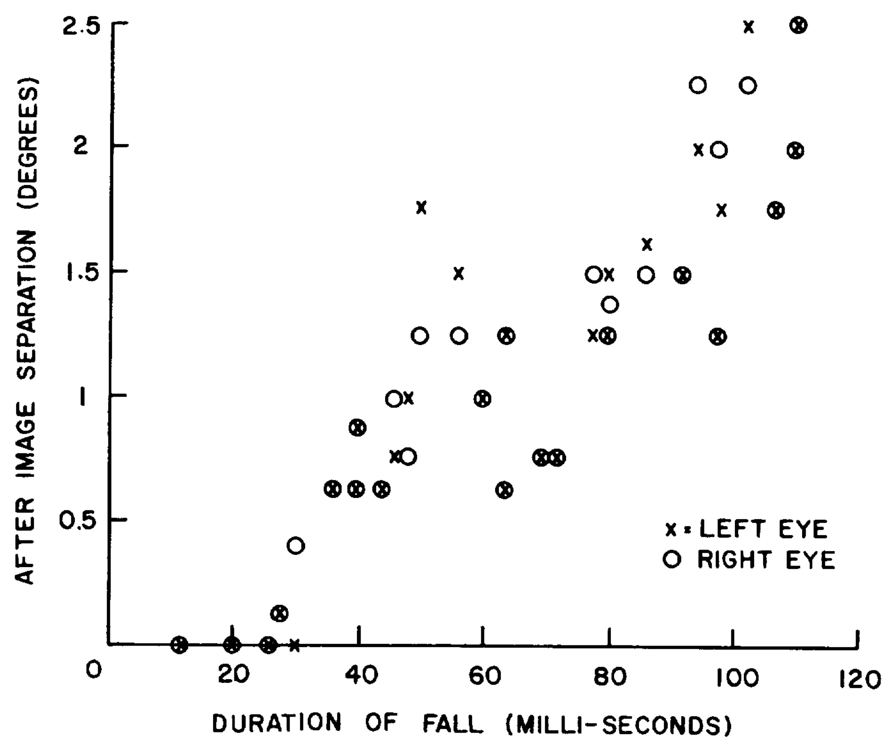


Figure 6

DISCUSSION

It is evident from the results of our experiments that this illusion is seen less consistently if at all by the subjects who had defective labyrinthine function, whereas normal subjects did see the elevator illusion and in the same direction as that described in the original observations.

There is, of course, in the elevator no change in direction of the resultant force, and proprioceptors consequently give information relating only to a vertical change without any tilt. As one would expect, therefore, the elevator illusion consists only of a vertical translational movement. This, together with the fact that vestibular defective subjects did not experience this illusion, plus the observation that the eye movement recorded in normal subjects occurred within some 20-30 milliseconds of the change from 1 G to 0 G, is strong evidence that the essential element of this illusion is an involuntary eye movement of reflex character arising from vestibular stimulation.

There is certainly a generic similarity between this and the oculogravic illusion, as described by Graybiel (2), but to pursue this comparison one must look more closely at the oculogravic illusion in which the predominant and typical observation is that the visual environment is tilted, with the observer, and relatively to what he perceives through his proprioceptors as being the vertical. There is also, however, at the beginning of the stimulus, and almost before this tilt can be observed, a brief illusion of distinct upward movement which is best seen if one looks at a small light source in darkness. Thus, the oculogravic illusion can be regarded as consisting of two parts: the first a transient or dynamic phase, being the movement illusion associated with the change in acceleration, while the second, prolonged or static phase, is the tilt illusion associated with a change in direction of the perceived vertical.

The fact that vestibular defective subjects do occasionally seem to experience the oculogravic illusion, but in an atypical form, suggests that although the stimulus mainly responsible for the phenomenon is applied through the labyrinth, responses from non-otolithic postural reflexes may also play a part. It may well be, therefore, that the illusion perceived predominantly through the non-otolithic route may be the static or tilt phase of the illusion, while that perceived predominantly as a result of labyrinthine stimulus is the dynamic phase.

On the basis of the present observations, it seems that the elevator illusion is similar to the dynamic phase of the oculogravic illusion and that both may be due to otolithic stimulation.

One could now explain the apparent lack of adaptation to the tilt or static phase of the oculogravic illusion since this phase would be related to a steady change of the environment relatively to the direction of the perceived vertical. On the other hand, the apparent rapid adaptation to the elevator illusion may be due to the fact that there is something for the eyes to fixate so that involuntary eye movements may be corrected.

It still has to be determined, however, whether in the absence of visual fixation, and under conditions of prolonged weightlessness or altered G the eyes will remain deviated, or whether this reflex movement is associated not with the stimulus of changed but of changing acceleration.

From the results of this experiment one can unfortunately not determine, with precision, the time relations of stimulus and eye movement. An indication of this relationship, however, can be obtained by comparison of results with two points in the acceleration profile which one would expect to be associated with eye movement. The first is at the onset of the fall at time 0 millisecond and the second is the trough in the acceleration profile which occurs at 48 milliseconds. If one expects a reduction in G to be associated with the occurrence of an upward eye movement, then an increase in G should be associated with a downward eye movement, and at the trough occurring at 48 milliseconds, one might expect the deviation of the eyes to be minimal. In Figures 2 and 4 it will be seen that there is indeed a point occurring at 68-70 milliseconds at which deviation of the eyes does return to a minimal value. If this minimal deviation is indeed associated with the trough in the acceleration profile, this would mean that the latent period was only about 30 milliseconds.

More obvious is the time at which the first eye movements are detected after the start of the drop. From Figures 1 and 2 it will be seen that there is no appreciable movement before 20 milliseconds and that by 40 milliseconds, the eyes have begun to deviate so that one might take this estimate of the latent period as being between 20 and 40 milliseconds.

Thus, although the time relations cannot be determined with accuracy, it does seem that eye movements are occurring 20-30 milliseconds after the appearance of the stimulus of linear acceleration acting in a constant direction and that these eye movements are of labyrinthine (otolithic) origin. It is probable that they appear only because the reflex arc has been unable to maintain fixation when the stimulus has changed rapidly. One would therefore expect fixation to be re-established within about 200 milliseconds. The probable mechanism for the appearance of movement in this illusion, when there is no demonstrable eye movement, forms part of a subsequent paper (4).

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